Cross-section Dependent Top Quark Mass Measurement in Dileptonic Channel using Template Method in 1.2 fb^{-1}

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URL http://www-cdf.fnal.gov
(Dated: June 20, 2007)

We present a cross-section dependent top quark mass measurement in the dilepton channel. This measurement is sensitive to the kinematics of the events and the observed number of events. The unconstrained system of dilepton events is solved using the $t\bar{t}$ longitudinal momentum, and the top quark mass is reconstructed for each event. In 1.2 fb^{-1} of data, we measure the top mass $M_{top} = 170.0\ ^{+4.2}_{-3.9}\ (stat.) \pm 2.6\ (syst.) \pm 2.4\ (theory)$ GeV/c^2 from the 70 events passing the event selection and the mass reconstruction.

Preliminary Results

I. INTRODUCTION

The top quark mass measurement is one of the most important measurements at Tevatron. Its mass is close to the scale of electroweak symmetry breaking which raises a possibility that perhaps the top mass is not generated by the SM Higgs mechanism in the same way as postulated with other fermions. The top quark mass has a significant contribution to radiative terms in theoretical calculations of many observables. This is especially important on the predictions of the Higgs boson mass. The top quark mass also enters into various alternative models of particle physics. A more precise measurement can be used to further refine or reject many of those theories.

At the Tevatron collider, the main production mechanism for the top quark is the pair production via quark annihilation or gluon fusion. The top quark decays into a b-quark and a W-boson with a branching ration nearly 100%. In dileptonic channel, the two resulting W-bosons decay leptonically. Such events have little background contamination and only two possible parton-jet assignments, but they also have low statistics and two neutrinos escaping detector.

This note describes the first top quark mass measurement which uses information from cross-section – top mass dependence. This measurement is sensitive to the shape of the reconstructed top mass distribution as well as the observed number of events. The measurement is performed in dileptonic channel using data collected by the the CDF detector [1] at the Fermilab Tevatron. The data sample corresponds to a total integrated luminosity of 1.2 fb^{-1}. Similar measurement without cross-section dependence is described in [2].

II. DATA SAMPLE & EVENT SELECTION

The signiture of dileptonic $t\bar{t}$ events consist of two high-p_T leptons, missing transverse energy ($\not\!\!E_T$) from the undetected neutrinos, and two jets coming from the hadronization of the b-quarks. Additional jets are often produced via initial state (ISR) and final state radiation (FSR).

The data are collected with an inclusive lepton trigger that requires an electron with E_T >18 GeV/c^2 or a muon with P_T >18 GeV/c. After full event reconstruction, the electron is required to have E_T >20 GeV/c^2 and the muon is required to have P_T >20 GeV/c.

One lepton must pass strict lepton identification requirements and be isolated. A lepton is isolated if the total transverse energy within cone $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.4$, minus the candidate lepton E_T, is less than 10% of the candidate lepton E_T. Tight electron candidates have a well-measured track pointing at an energy deposition in the calorimeter. In addition, the candidate's electromagnetic shower profile must be consistent with that expected for electrons. Similarly, tight muon candidates must have a well-measured track linked to hits in the muon chambers and energy deposition in the calorimeters consistent with that expected for muons.

The second lepton candidate is selected the same way as the first lepton, with the exceptions that it does not need to be isolated and muon identification requirements are relaxed. The tight and loose lepton have to be oppositely charged.

We require candidate events to have $\not\!\!E_T > 25$ GeV after correcting for all escaping muon momenta. If $\not\!\!E_T \leq 50$ GeV, we further require that the $\not\!\!E_T$ vector is at least 20° apart from the closest lepton or jet. The event is required to have at least two jets with $E_T > 15$ GeV and which are detected in $|\eta| < 2.5$, where the jet is defined as a fixed-cone cluster with a cone size of R = 0.4.

Moreover, we require the scalar transverse energy sum $H_T > 200$ GeV, and the events with cosmic rays, conversions or Z events are rejected. The expected number of events passing the event selection is shown in Table I.

	signal	background
Total	55.95±4.26	25.56±5.54
b-tagged	30.3±2.5	2.8±1.1
non-tagged	25.7±2.1	22.8±5.0

TABLE I: Expected sample composition in 1.2 fb^{-1}.

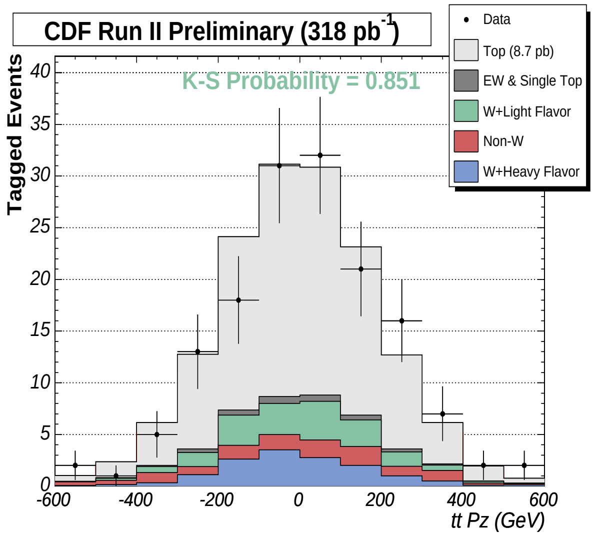

FIG. 1: Longitudinal momentum of data $t\bar{t}$ events in lepton+jets channel.

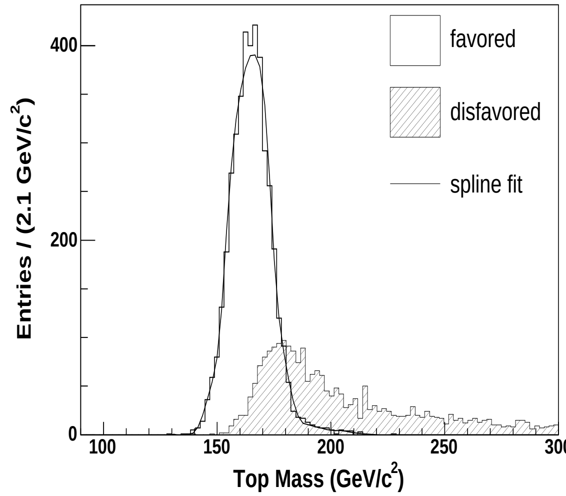

FIG. 2: Reconstructed top mass distributions for one event. Two histograms correspond to two possibilities to pair a lepton and a jet.

III. TOP MASS RECONSTRUCTION

A. Top mass information from kinematics

In dilepton channel, the system is underconstrained for top mass fitting. The momentum components of the charged leptons and jets can be measured with the detector, as well as the two components of $\not{E}_T$. The masses of the final state b-quarks and leptons are known, and the neutrinos are assumed to be massless. By further assuming $W^{\pm}$ boson masses, as well as that t and $\bar{t}$ masses are equal, we can write 23 equations for 24 quantities.

The system can be solved by using a distribution which is independent of the top mass. In this analysis, we take the momentum z-component of the $t\bar{t}$ system, $P_z^{t\bar{t}}$. This distribution is almost independent of the top mass, zero-centered Gaussian with $\sigma \approx$ 195 GeV/c.

The measured quantities have experimental uncertainties. We smear jet energies, $\not{E}_T$ and $P_z^{t\bar{t}}$ by randomly drawing these quantities 10000 times from a distribution which is centered at the measured value and has the width of the expected error. The kinematic equations are solved for each set of smeared quantities, yielding to a distribution of possible reconstructed top masses.

There can be up to 8 solutions to the kinematic equations. Four possible solutions correspond to different neutrino solutions. We select the neutrino solution which has the smallest effective mass of the $t\bar{t}$ system. The other two possible solutions correspond to two possible ways to associate a b-jet to a b-quark. We select the combination which has higher mass reconstruction probability. The reconstructed top mass distributions for the favoured and disfavoured b-jet – b-quark combinations are shown in Figure 2. The most probable value from the favoured distribution is considered as the reconstructed top mass for the given event. The normalized distribution of reconstructed top masses is called a template.

The final step in top mass reconstruction chain is the likelihood fit. We fit the reconstructed top mass values of the data candidates to the Monte Carlo templates.

1. *Top Mass Templates for Signal and Background*

We create signal templates using Pythia Monte Carlo samples with the input top masses from 150 GeV to 200 GeV with 2 GeV steps. The fitting function $f(m_{Top}^{rec}, m_{Top}^{orig})$ is a combination of Gaussian and Landau functions and depends on reconstructed mass, m_{Top}^{rec}, and the given true top mass, m_{Top}^{orig}. The parameters of this function are assumed to have linear dependence on the true top quark mass. The signal template for b-tagged events is shown in Figure 3, and the signal template for non-tagged events is shown in Figure 4.

The dilepton channel has the advantage of a good signal-to-background fraction compared to the other decay

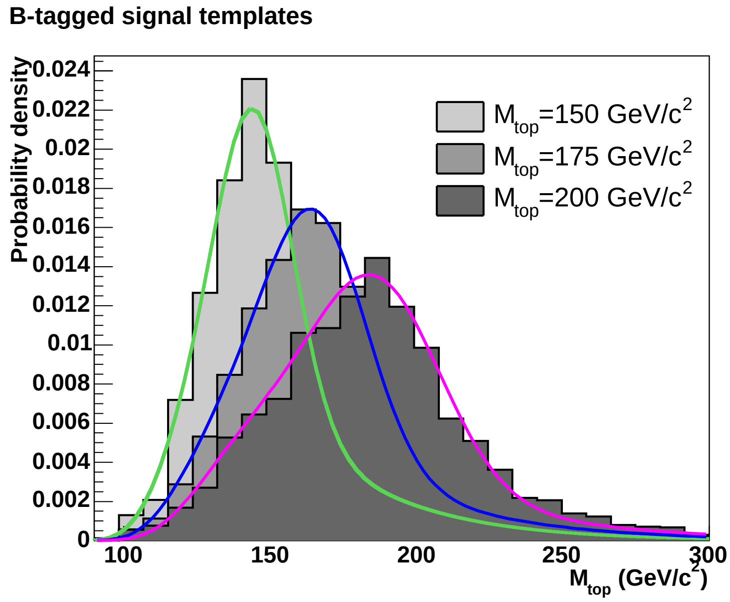

FIG. 3: B-tagged signal templates and parametrisations

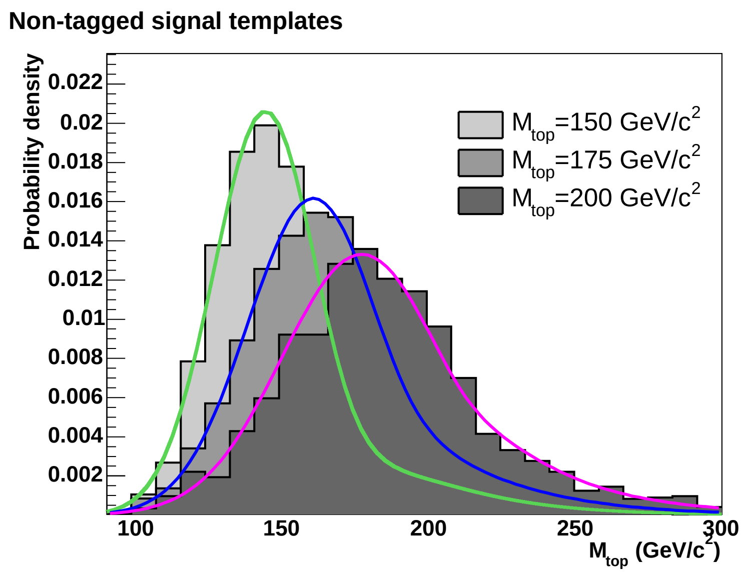

FIG. 4: Non-tagged signal templates and parametrisations

channels. The dominant backgrounds in the dilepton channel are diboson (WW,WZ,ZZ) production, Drell-Yan ($q\bar{q} \rightarrow Z/\gamma^* \rightarrow \ell^+\ell^-$) production and fake leptons coming from $W \rightarrow \ell\nu + jets$ events where a jet is falsely reconstructed as a lepton candidate.

To take into account the contribution from background events to the top mass reconstruction, we create background templates from each background process. These background templates are combined according to their expected yield. The combined background template is shown in Figure 5. We use the same background template for b-tagged and non-tagged events.

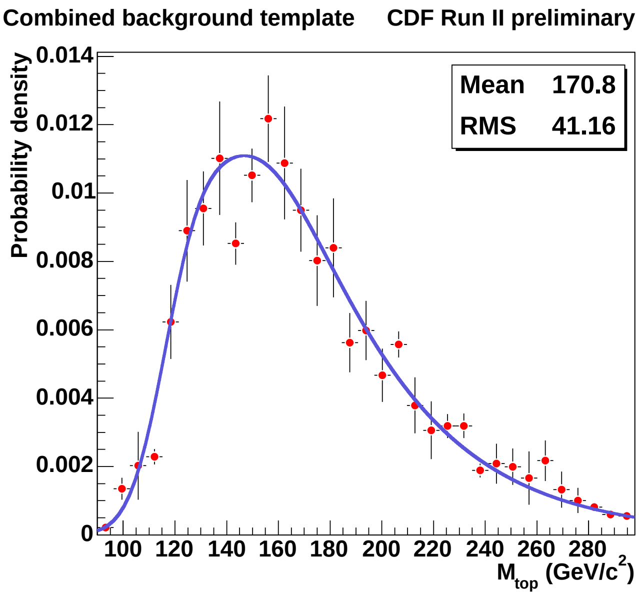

FIG. 5: Combined background template.

B. Top mass information from number of events

The number of signal events depends on the top mass. Therefore the observed number of events can be used to measure the top mass. The top mass dependence comes from the theoretical cross-section and the acceptance of $t\bar{t}$ events. The number of signal events passing the event selection and the mass reconstruction can be expressed as a function of top mass according to the formula

$$n_s(m_{top}) = \sigma_{t\bar{t}}(m_{top}) \cdot a(m_{top}) \cdot \mathcal{L} \cdot p^{rec}_{mass} \tag{1}$$

where $\sigma_{t\bar{t}}(m_{top})$ is the $t\bar{t}$ cross-section, $a(m_{top})$ is the acceptance, $\mathcal{L}$ is the integrated luminosity, and p^{rec}_{mass} is the mass reconstruction probability.

We fit a formula of form $\sigma(m_{top} = 175\ \mathrm{GeV/c^2}) \cdot \exp((175 - \mathrm{m_{top}})/\mathrm{p0})$ [5] to three top mass – cross-section pairs [6]. The function is shown in Figure 6.

The acceptance of b-tagged and non-tagged events was studied from $t\bar{t}$ Monte Carlo with different top masses. The Monte Carlo acceptance was scaled with scale factors which arise from measured differences between Monte Carlo and data. The acceptances as a function of top mass are shown in Figure 7.

The integrated luminosity for b-tagged sample is 1118 pb^{-1} and 1189 pb^{-1} for non-tagged sample. The mass reconstruction probability is p^{rec}_{mass}=0.91 for both the b-tagged and non-tagged sample, and it does not have top mass dependence.

C. Likelihood fit

We use a maximum likelihood method to get the final top quark mass estimate. The reconstructed top mass distribution from data is compared to the parametrisations of the signal and background templates, and the number of events is compared to the expected number of events. The comparison is performed using the formula:

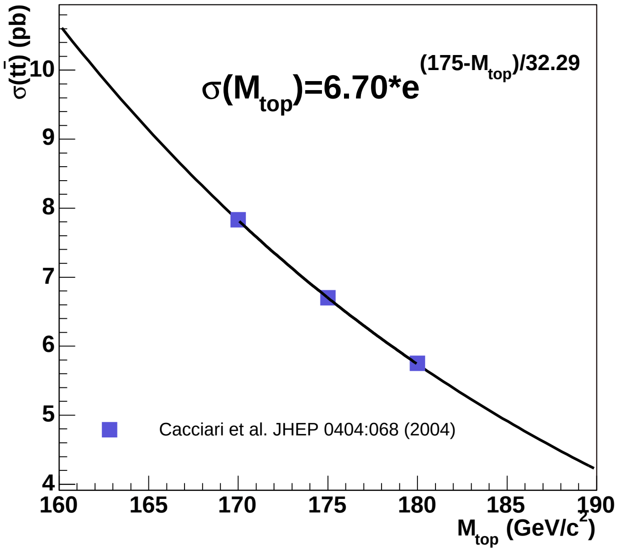

FIG. 6: Theoretical cross-section.

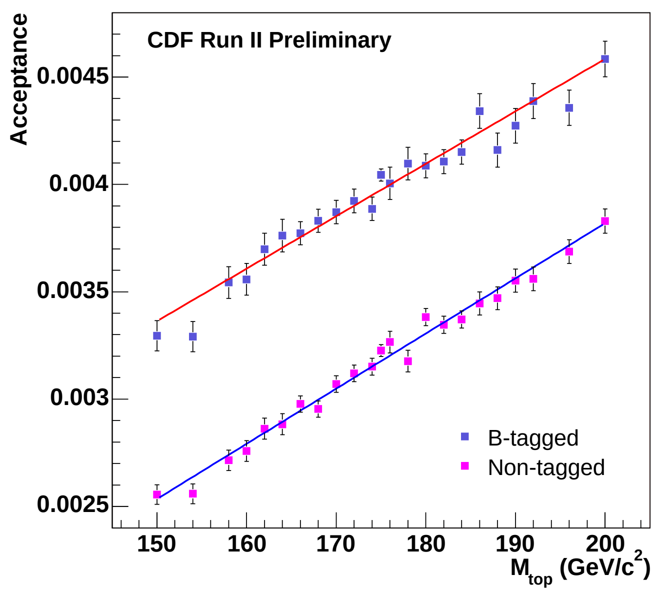

FIG. 7: Acceptance of b-tagged and non-tagged $t\bar{t}$ events.

$$
\begin{aligned}
n_s &= \sigma_{t\bar{t}}(m_t^{orig}) \cdot a(m_t^{orig}) \cdot \mathcal{L} \cdot p^{rec}_{mass} \\
\mathcal{L} &\equiv \mathcal{L}_{b-tagged} \times \mathcal{L}_{non-tagged} \\
\mathcal{L}_{sub-sample} &\equiv \mathcal{L}_{shape} \times \mathcal{L}_{nev} \times \mathcal{L}_{bg} \\
\mathcal{L}_{shape} &\equiv \prod_{i=1}^{n} \frac{n_s \times f_s({m_{t_i}}^{rec}, m_t^{orig}) + n_b \times f_b({m_{t_i}}^{rec})}{n_s + n_b} \\
\mathcal{L}_{nev} &\equiv \frac{e^{-(n_s+n_b)}(n_s+n_b)^N}{N!} \\
-\ln \mathcal{L}_{bg} &\equiv \frac{(n_b - n_b^{exp})^2}{2\sigma^2_{n_b}}
\end{aligned}
$$

where the top mass m_t^{orig} and the number of background events n_b are fit parameters. The number of background events is Gaussian constrained by $\mathcal{L}_{bg}$ and the Poisson term $\mathcal{L}_{nev}$ makes sure the total number of events $n_s + n_b$ is in agreement with the number of data events.

IV. TESTING THE METHOD WITH PSEUDOEXPERIMENTS

We perform pseudoexperiments to see if our method gives the correct estimate of the top mass and its error. We randomly choose expected number of signal and background events from signal and background templates, and perform likelihood fit on the selected set of events. We repeat this procedure 10000 times. The number of events in each pseudo-experiment is Poisson fluctuated around the expected value.

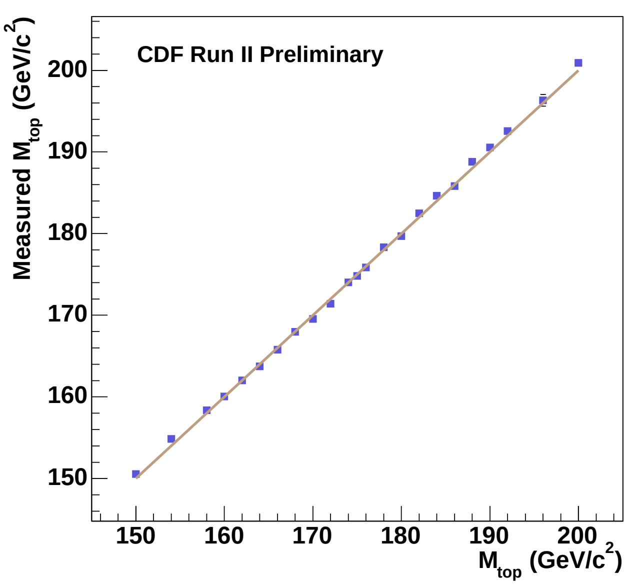

FIG. 8: The mass dependence of the measured top mass.

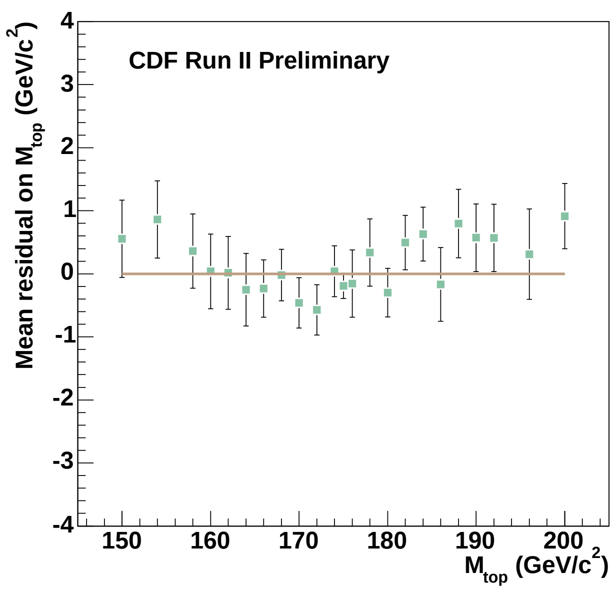

FIG. 9: The mass dependence of difference between original and reconstructed mass.

To see if our estimate of the error on top mass is correct we looked at the pull variable. The pull is defined as the ratio of the difference between original and reconstructed mass and the average of the estimated positive and negative error on the top mass. The plots for mass dependence of pull mean and pull width are shown in Figures 10 and 11.

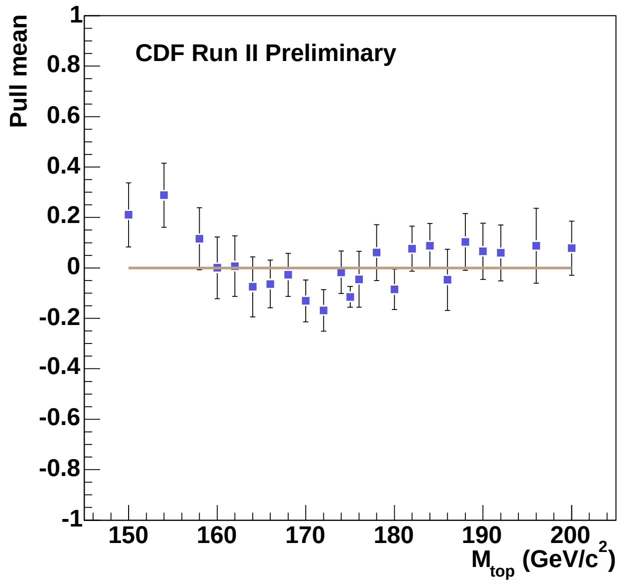

FIG. 10: The mass dependence of pull mean.

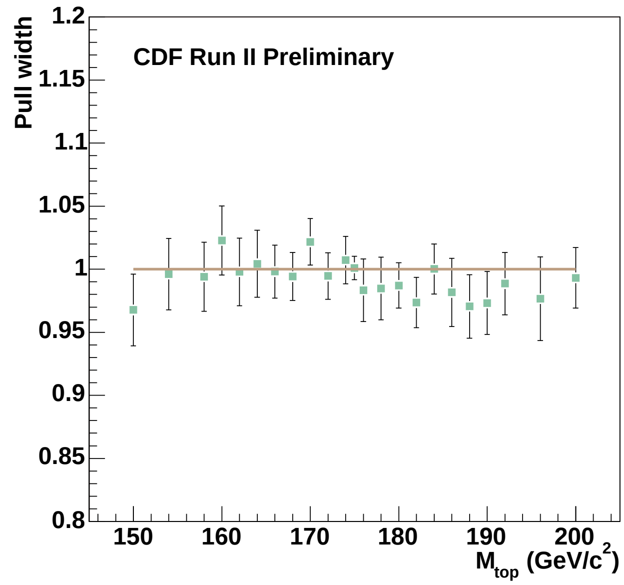

FIG. 11: The mass dependence of pull width.

V. SYSTEMATIC UNCERTAINTIES

Top mass determination using this method is sensitive to the templates as well as the number of events. Systematic shifts on measured top mass may arise whenever the simulation does not accurately model the kinematics or the expected number of events. Systematic uncertainties are estimated by adjusting the kinematics of the input events or the number of events in pseudo-experiments, or both at the same time.

In the systematic study of luminosity uncertainty on top mass, the Monte Carlo based estimates of numbers of events were shifted by $\pm6\%$. The uncertainty on top mass is 1.1 GeV/c^2. All the other sources which cause uncertainty in the expected numbers of events, but not in the kinematics of the events, were shifted by $\pm1\sigma$, the expected numbers of events were recalculated, and pseudo-experiments were performed. The separate uncertainties were added in quadrature, yielding to 0.5 GeV/c^2 uncertainty from acceptance and 0.9 GeV/c^2 uncertainty from expected number of background events. The uncertainty from mass reconstruction probability is 0.5 GeV/c^2.

We have studied the uncertainty from jet energy scale by changing the corrections by $\pm1\sigma$. The total systematics coming from this source is 1.5 GeV/c^2. This error is related to light quark jets, so we evaluated an additional systematic error due to b-jet energy scale and found it to be 0.9 GeV/c^2. Lepton p_T was varied by $\pm1\%$, which leads to the systematic uncertainty of 0.3 GeV/c^2.

We compared the HERWIG [3] and the PYTHIA [4] and assigned the systematic error due to different types of generators to be 0.5 GeV/c^2. The initial and final state radiations (ISR and FSR) uncertainties are estimated using PYTHIA Monte Carlo samples in which QCD parameters for parton shower evolution are varied based on the studies of the CDF Drell-Yan data. The systematic uncertainty due to the ISR and FSR are 0.3 GeV/c^2 for both sources. Another systematic error is coming from using different parton distribution functions (PDF). We have considered 20 pairs of CTEQ6 $\pm1\sigma$ uncertainty sets, two sets of MRSTs for different Λ_{QCD} values, and the difference in CTEQ and MRST PDF groups. The total systematic from the PDFs is 0.6 GeV/c^2. We also evaluated the systematic error related to the template statistics. We Poisson fluctuated number of events in each bin, and performed pseudo-experiments with the changed template. The procedure was repeated 100 times. The systematic uncertainty due to the signal template statistics is 0.2 GeV/c^2 and due to the background template statistics is 0.4 GeV/c^2. We also estimate an uncertainty coming from possible imperfections in modelling the Drell-Yan and fake background, as well as an uncertainty coming from using the general background template for the b-tagged events. The total background template shape uncertainty on top mass is 0.3 GeV/c^2.

The systematic uncertainties are summarized in Table II.

CDF Run II preliminary

Source	ΔM_{top} (GeV/c^2)
Expected number of events	1.6
Jet and lepton energy scale	1.8
Signal modeling	0.9
Background modeling	0.3
Template statistics	0.4
Total	2.6

TABLE II: Summary of systematic uncertainties.

VI. RESULTS

We apply the loglikelihood fit to the 70 data events which pass the event selection and the mass reconstruction requirements. 33 of the events are b-tagged and 37 are non-tagged. Setting the number of b-tagged background events to 2.2±1.1 and the number of non-tagged background events to 17.8±4.7, the result of the likelihood fit is

$$M_{top} = 170.0^{+4.2}_{-3.9}(stat.) \quad \mathrm{GeV}/c^2$$

where the amount of background as a result of the fit is 2.2±1.0 b-tagged background events and 15.2±3.5 non-tagged background events.

Figure 12 shows the measured cross-section dependent top mass together with the top mass measurement without cross-section dependence, measured cross-section, and the theoretical $\sigma_{t\bar{t}}$.

The expected statistical error distribution is shown in Figure 13.

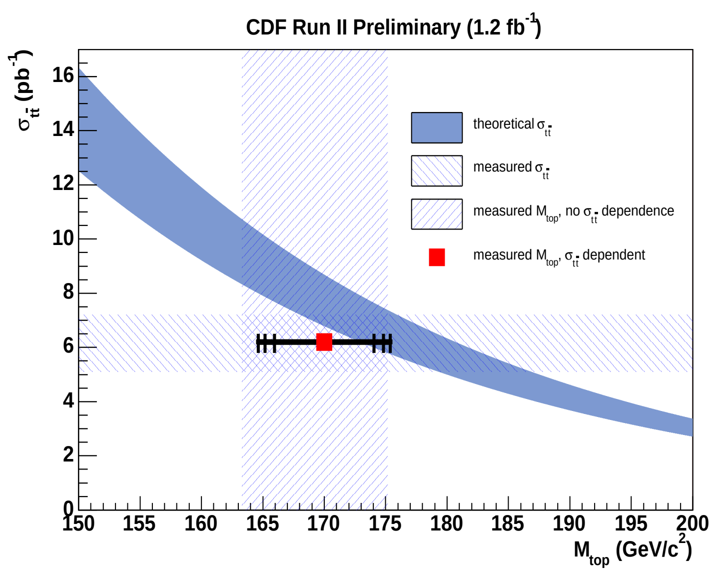

FIG. 12: Cross-section and template top mass measurements in dilepton channel. The hatched areas show independent measurements of cross-section and top mass. The red dot with error bars show the template top mass measurement where the cross-section information is added. Blue band is for theoretical $\sigma_{t\bar{t}}$.

VII. CONCLUSION

We have measured the top quark mass in dileptonic channel using 1.2 fb^{-1} of data collected by the CDF experiment. The measured top mass is $M_{top} = 170.0^{+4.2}_{-3.9}(stat.) \pm 2.6(syst.) \pm 2.4(theory)$ GeV/c^2.

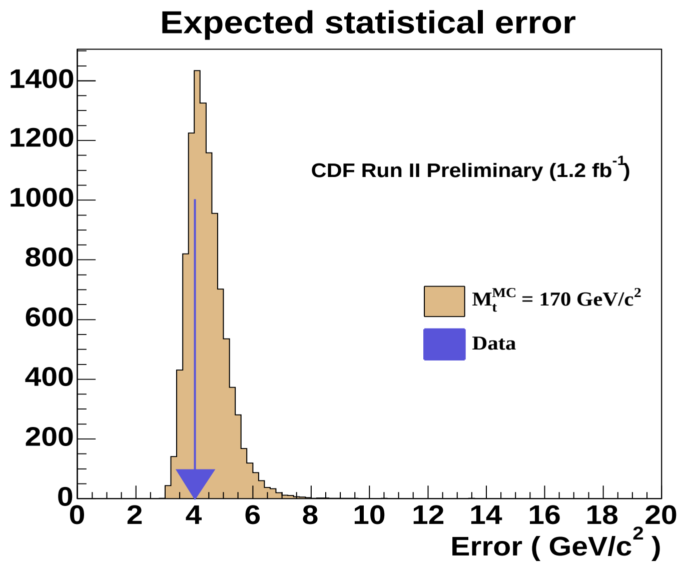

FIG. 13: Expected statistical error and error obtained from the data.

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium für Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comisión Interministerial de Ciencia y Tecnología, Spain; in part by the European Community's Human Potential Programme under contract HPRN-CT-2002-00292; and the Academy of Finland.

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